SECTION XII

HYDROLOGIC-NUTRIENT BUDGET

An important step in the development of a successful lake restoration action plan is the accurate calculation of the hydrologic and nutrient budgets. These data provide insight relevant to the nutrient dynamics of the lake. The magnitude and frequency of hydrologic contributions affect nutrient loading, sedimentation and lake flushing rate. The nutrient budget quantifies the relative importance of various nutrient sources on the lake's annual nutrient load, and is the principal component in the calculation of lake trophic state.

A. HYDROLOGIC BUDGET

The hydrologic budget for Lake Hopatcong was calculated from tributary flow, surface runoff, precipitation, evaporation, and groundwater infiltration data.

1. Precipitation/Evaporation

Precipitation data was obtained from NOAA monitoring records for the general Lake Hopatcong area (NOAA, 1981; NOAA, 1982). These data were compared to rainfall data collected by LHRPB volunteers. Both data sets were found to agree reasonably for those months where simultaneous collections were available for comparison (Table 45). The total precipitation which fell during the study period (August, 1981 to August, 1982) amounted to 108.65 cm. This is approximately 12 cm less than the average annual precipitation for the basin (Table 46). Surface runoff to the lake, hydrologic loading due to precipitation falling directly into the lake, and normalized stream flows were calculated on

Table 45

RAINFALL FOR LAKE HOPATCONG BASIN (CM)

Month	Historical 1951-1973	1981-1982 LHRPB	1981-1982 NOAA	(+/-) Difference Between NOAA and LHRPB
August 1981	12.75	-	3.73	-
September 1981	9.39	-	6.95	-
October 1981	9.39	-	11.10	-
November 1981	11.40	-	3.66	-
December 1981	10.50	-	10.44	-
January 1982	7.73	-	10.30	-
February 1982	8.17	-	8.71	-
March 1982	10.08	-	5.99	-
April 1982	10.78	11.81	13.21	+1.40
May 1982	9.34	7.95	8.05	+0.10
June 1982	9.74	16.99	16.10	-0.80
July 1982	11.05	10.54	10.41	-0.13
Total	120.34		108.65	

ADDITIONAL DATA

Month	Historical 1951-1973	1981-1982 LHRPB	1981-1982 NOAA	(+/-) Difference Between NOAA and LHRPB
August 1982		12.09	13.45	+1.36
September 1982		10.01	8.95	-1.06
October 1982		3.56	3.65	-0.09

Table 46

PRECIPITATION-EVAPORATION

EVAPORATION FROM LAKE

(1) 32.5"/yr

(2) 69% of which occurs between May and September

32.5"/yr = 82.55 cm yr^{-1} mean

$$\frac{82.55 \text{ cm}}{120.35 \text{ cm}} \times \frac{x}{108.65 \text{ cm}} = 74.5 \text{ cm lost in 1981-1982}$$

108.65 cm - actual precipitation
\- 74.5 cm - estimated evaporation
34.15 cm - net gain via precipitation

Surface area of lake = $10.87 \times 10^6 m^2$

Net gain via precipitation = 34.15 cm yr^{-1} = 0.3415 m yr^{-1}

TOTAL INFLOW DUE TO RAINFALL

$3.712 \times 10^6 m^2 yr^{-1}$

the basis of the measured rainfall data. The hydrologic load associated with precipitation into the lake was corrected for evaporation using the evaporation isopleths developed by Hely, et al (1961) for Morris and Sussex Counties.

2. Tributary Inflow

Flows eminating from Lake Shawnee and from the stream which drains sub-basin 10 (LHS 4) were monitored. This represents approximately 38% of the total watershed, and therefore a sizable portion of the lake's hydrologic load. The height of water flowing over the Lake Shawnee dam was measured and utilized in a modified broad crested weir formula to determine daily flows. The discharge of the small stream which drains sub-basin 4 was monitored through the use of a 90^0 V-notch weir. Weir readings were recorded daily and converted to flow using the appropriate discharge formula (Anon, 1978).

Hydrologic inputs from the remainder of the basin were determined using an empirical precipitation-stream discharge formula (Eq. 6), based on measured average monthly precipitation data. This approach was necessitated as the majority of inflow to the lake is non-gagable. The inflow data obtained by this method is a reasonble estimate, comparable, in terms of inherent error, with measured discharge methods (Scheider, et al, 1979).

Unfortunately, the weir and dam data, due to a variety of reasons, were deemed inadequate for incorporation into the hydrologic budget. As a result, all tributary inflows were computed using the empirical-precipitation formula. Using this method, tributary inflow for the study year was calculated to be 19.61 x $10^6 m^3 yr^{-1}$. Surface runoff directly entering the lake accounted for an additional 3.47 x $10^6 m^3$. Precipitation falling directly into the lake totaled 11.81 x $10^6 m^3$, but

Table 47

HYDROLOGIC BUDGET FOR
LAKE HOPATCONG

Inflow	$10^6 m^3 yr^{-1}$	% Total
All Tributaries*	19.61	49.4
Surface Runoff which Directly Enters Lake**	3.47	8.7
Precipitation-Evaporation	3.72	
Groundwater Infiltration	12.89	9.4
TOTAL INFLOW	39.69	100.00
Outflow		
Musconetcong River	39.69	100.00
TOTAL OUTFLOW	39.69	

*Flow obtained using empirically generated data (Q = ABC), normalized using N.E.S. Methodology (USEPA, 1975).

**Flow obtained using empirically generated data (Q = ABC).

$8.09 \times 10^6 m^3$ were lost due to evaporation from the lake's surface. The total hydrologic inflow for the study year was thus $26.8 \times 10^6 m^3$ (Table 47).

3. Outflow

Outflow from the lake, measured on a daily basis by Lake Hopatcong State Park personnel, totals $39.69 \times 10^6 m^3 yr^{-1}$ for the period of August 1981 through July 1982. It should be noted that outflow from the lake is the combined result of flow over the lip of the dam and through the lake's floodgates. Outflow through the flood gates is regulated by personnel of Lake Hopatcong State Park. Minimum discharge from the lake is mandated by law to be $2.9 \times 10^4 m^3 d^{-1}$. During the winter of 1981-1982 the lake was drawn down approximately 2.5 m in order to prevent ice damage to docks and launches. The outflow from the lake therefore represents water in excess of the lake's volumetric capacity as well as water artificially released during the drawn down operation (Table 48).

4. Groundwater

The difference between total hydrologic losses and measured or calculated hydrologic inputs is $12.89 \times 10^6 m^3 yr^{-1}$. This difference is attributable to the groundwater inflow to the lake and its tributaries which occurred during the study year. The accuracy of this value is in part verified through the use of groundwater runoff coefficients developed by Posten (1982) for predominately forested watersheds in Passaic County, New Jersey. The results of this analysis indicate that $15.87 \times 10^6 m^3 yr^{-1}$ of groundwater is contributed to Lake Hopatcong under <u>average</u> conditions, as based on a groundwater runoff rate of $7.925 \times 10^2 m^3 d^{-1} km^{-1}$, applied to a watershed area of $54.827 \ km^2$. This groundwater inflow data represents the hydrologic inputs to both the lake and its tributaries. As the tributary hydrologic loads are based on surface runoff, it is necessary to include the groundwater inputs, in order to develop a complete hydrologic budget. The computed average value agrees quite well with the estimated groundwater inflow for the study year. Total precipitation for the study period was less than the average annual rainfall for the area, thus explaining the discrepancy between the observed and predicted groundwater contributions. Thus, our groundwater input value, although derived as the difference between hydrologic loss and surface hydrologic inputs, appears to be a reasonably valid estimate.

Table 48

OUTFLOW FROM LAKE HOPATCONG

Month	Volume of Water Discharged $m^3 \times 10^5 \cdot month^{-1}$
August 1981	2.32
September 1981	2.67
October 1981	4.82
November 1981	11.4
December 1981	77.6
January 1982	64.3
February 1982	53.6
March 1982	35.0
April 1982	30.6
May 1982	38.4
June 1982	51.9
July 1982	24.3
TOTAL	$3.969 \times 10^7 m^3 yr^{-1}$

B. NUTRIENT BUDGET

The nutrient budget of the lake was developed from the loading data associated with point sources, septic tanks, wet and dryfall directly into the lake, gaged and non-gaged tributary inflow, and surface runoff directly entering the lake. For total phosphorus, the internally generated load, resulting from the liberation of sediment bound phosphorus under anoxic conditions, was also accounted for in the nutrient budget. The means by which these various components of the nutrient budget were calculated, are discussed in detail in the previous sections.

The annual total nitrogen (TN), total suspended solids (TSS), and total phosphorus (TP) loads contributed to the lake during the study period are 92,866.5 kg TN yr^{-1}, 3,943,225 kg TSS yr^{-1}, and 3,884.8 kg TP yr^{-1}. Of the annual TN load 23.6% is contributed by non-point sources such as direct surface runoff and tributary loading (Table 49). Septic tank leakage contributions account for 64.5% of the annual TN load, indicating that a very serious septic related problem exists in Lake Hopatcong. For phosphorus, surface runoff and septic leakage are the two main sources of total phosphorus to the lake (Table 49). Surface runoff inputs, accounted for by tributary loads, as well as runoff which directly enters the lake, are 38.1% of the annual TP load. Septic related inputs represent 37.7% of the annual TP load. The magnitude of the septic component of the lake's TP budget attests to the serious impacts on lake water quality resulting from the leakage of septic effluent into Lake Hopatcong. It also acknowledges the need to abate this load as addressed in the Upper Musconetcong River Basin Wastewater Facility Plan (PAS, 1983).

The point source load presently contributed to the lake are meager (Table 49). Three of the four STPs are facilities which service public schools. The population size, intermittency of flow, and generally low

Table 49

NUTRIENT - SEDIMENT BUDGET FOR LAKE HOPATCONG

Nutrient Sediment Source	Total Phosphorus		Total Nitrogen		Total Suspended Solids	
	kg yr^{-1}	% Total	kg yr^{-1}	% Total	kg yr-1	% Total
Non-Point Sources						
Gaged Streams*	339.0	8.0	6056.7	6.5	537973***	
Monitored Streams**	75.3	1.8	5336.6	5.8	848325***	
Remaining Non-Point Sources***	1202.4	28.3	10511.8	11.3	2556645	
Wet-Dryfall Directly to Lake	271.8	6.4	10870.0	11.7	0	
Septic Tanks	1600.6	37.7	59852.2	64.5	0	
Point Sources						
	165.3	3.9	239.2	0.3	281.7	
Internal Recycling						
Hypolimnetic Recycling	595.0	14.0	0		0	
TOTAL	4249.4		92866.5		3,943,225	

*Streams for which gaged flow data and nutrient/sediment concentrations measured. Does not account for load contributed by the Stanlick School STP.

**Streams for which flow data obtained empirically, and nutrient/sediment concentrations measured. Does not account for load contributed by the Mt. Arlington Knolls Apartment and Our Lady of the Lakes School STP.

***Non-monitored tributaries and surface runoff, loads calculated using U.A.L. methodology.

volumes of effluent discharged by these plants act to make their contributions minimal. In addition, effluent from the Arthur Stanlick School is discharged first to a marsh which in turn flows into Lake Shawnee. Both water bodies reduce the trophic impact of the effluent on Lake Hopatcong.

A deficit in the preparation of the lake's nutrient budget is the failure to account for loading during storm events. Although the loads generated with the empirical precipitation-stream flow formula accounts for some of the storm related inputs, the nutrient loads associated with the first flush storm inputs were not measured. Attempts were made to measure storm loadings, but the short time of concentration characteristic of most of the monitorable tributaries resulted in the first flush occurring prior to the initiation of the sampling operations. Tuffey and Trama (1975) have demonstrated that only high intensity storms (>4.0 cm total rainfall) generate a substantial increase in nutrient loading and that the majority of that load is associated with the first flush. Other studies also conclude that the first flush of storms contributes the majority of the nutrient/sediment loads (Wanielista, et al, 1982). The TP and TN therefore presented in Table 49 are actually conservative and probably underestimate the full extent of storm related loading to Lake Hopatcong.

For essentially the same reasons as mentioned above, the TSS load to Lake Hopatcong was generated using the U.A.L. methodology discussed in detail in Section X. The loads obtained using this method incorporate, to an extent, the storm related contributions. Nevertheless, the TSS loads listed in Table 49 are also conservative and most likely underestimate the total annual load. Measured baseline, low flow loads for TSS totaled 159,842 kg yr^{-1}. This load represents the actual contribution of sediments to the lake under non-storm conditions. The large difference between the total TSS load and the baseline load (3,783,383 kg yr^{-1}) is attributed to storm related inputs including overland surface runoff contributed directly to the lake. This difference may appear substantial, but it has been demonstrated that in semi-rural areas 2,250 kg $ha^{-1}yr^{-1}$ of soil are annually lost. For a watershed the size of Lake Hopatcong (1,087 ha) this amounts to a typical annual load of approximately 2,450,000 kg yr^{-1}.